

**Mass Transfer II**  
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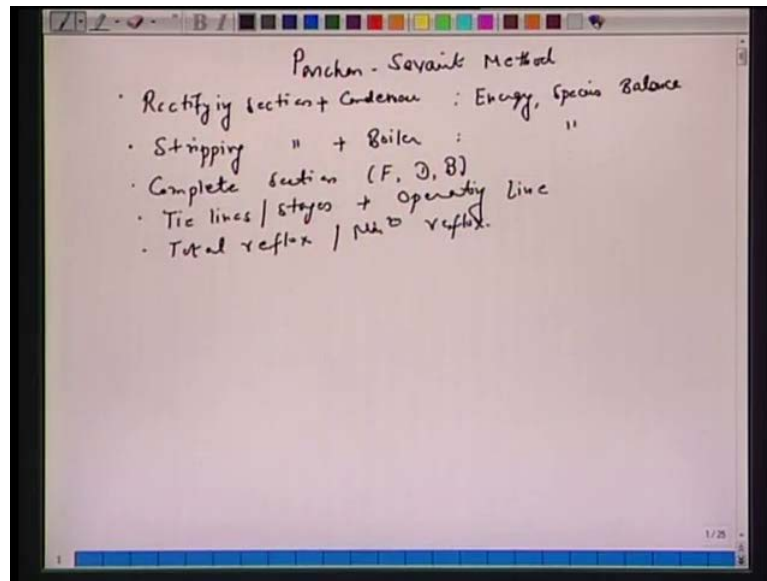
**Lecture No. # 18**

In the previous lecture, we completed our discussion on distillation column. So, essentially, what we did we segregated this column into three parts; we said we have the top column rectifying section, bottom column we had stripping sections and we had feed here. We made three balances for energy and species balance. One was for the top column stripping section including condenser, and the bottom we had the rectifying stripping sections including reboiler. And then we made the overall balance including feed, top product and the bottom product. And then we had  $H \times y$  diagram Ponchon-Savarit methods where we marked all the silent points, calculated how many number of plates are required to achieve that much of purification for the top product and for the bottom product.

We also talked about the reflux ratios, right? The reflux ratios quite important if you vary the reflux ratios the number, the plates required or the trays required in the distillation columns are also different, and then we had this total reflux, two extreme conditions total reflux and the minimum reflux ratios. And then we had one more important point is where the feed entry at what tray or underneath what tray feed makes the entry that also supposed to mark that point. Now we address the last part through an example.

We take up an example in today's lecture and where we calculate the reboiler load, condenser load, how many numbers of plates are required and what is the feed entry.

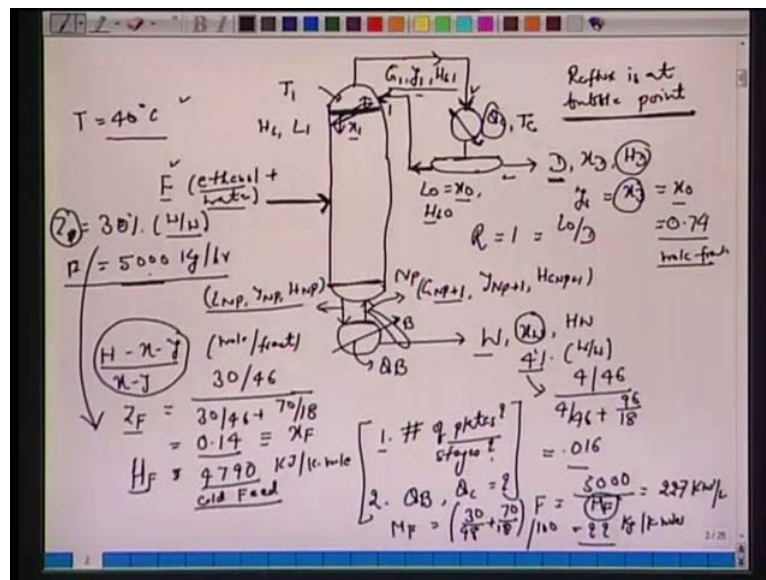
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So, let us look at the first example on this distillation column. So, this is on Ponchon-Savarit Method and what we had done, so far we had the Rectifying Section including Condenser; we made Energy balance and Species balance. Then we did the similar exercise for stripping section with boiler. Then we did, we made the balance on Complete Sections.

So, we had the feed, we had the top product and we had the bottom product. Then we talked about tie lines or the stages plus operating line. In the last class we have the last topic Total Reflux and another extreme case minimum reflux.

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So, in today's lecture we take this example, we have a distillation column. Let us draw distillation column. The problem statement reads that feed F if feed consists of binary components of ethanol and water mixture, and iterates 30 percent weight by weight. So, we can say Z F standing for x F or y F, it is 30 percent weight by weight. We will see how we will make these calculations. Temperature is given 40 degrees centigrade and feed flow rate F is 5000 kg per hour.

Now, it says the top product is withdrawn G, let us mark these points here. So, we have the first stage 1 here. So, this is G 1, y 1, H G 1. So, this is specks of the vapour which arrives at this condenser. The problem reads it is a total condenser that means we condense the entire vapour to this liquid. So, our top product which leaps here is a liquid. D, we have this x D and we have this H D, it reads the reflux is at bubble point. So, all it means this liquid or the product here D, and the reflux L 0 which goes to the column top is saturated. So, first thing if you recall from our discussion on this total condenser y 1 will be same as x D and x D will be same as x 0, because it is a total condenser. Enthalpy H D and H L 0 will be the same, because same product you are withdrawing and the fraction of it goes back to the distillation column.

Now, this y 1 which arrives here at this condenser will be at some temperature which will be different from the condenser temperature. So, here we must understand that from our previous discussion the y 1 which is leaving in the top column this will be in

equilibrium with the liquid which leaves this top column. If this is  $y_1$  and this is now  $x_1$ ,  $x_1$  is different from  $x_0$ . So, the temperature of this top column is also different from the temperature of this condenser. In other words even if with the problem is bubble refluxes at the bubble point this  $y_1$  which we have here and this vapour which arrives here is not at equilibrium with this liquid.

So,  $y_1$  and  $x_1$  or  $x_0$  here they will not lie at this tie points in fact  $y_1$  is in equilibrium with this experiment we will talk about this and mark, we have to be very careful with this statement here. All it means reflux at the bubble point means this  $x_0$  or  $x_D$  will lie at the saturated liquid enthalpy curve.

That is one thing we will come back to this, reflux ratio is given as 1. So,  $R$  is 1 and from our definition of  $R$  is nothing but  $L_0$  over  $D$ . Now we have this bottom product so, this liquid which trickles from the top part of it is vaporized and send back to this the last column or last plate that is  $N P$ . The specs for this vapour would be  $G_{N P + 1}$ ,  $N P + 1$  stands for a theoretical plate for this boiler then  $Y_{N P + 1}$ , we have  $H_{G_{N P + 1}}$  and this vapour now will be in equilibrium with the top bottom product  $W$  mole fraction  $X_W$  and  $H_W$ .

So this vapour and liquid they are in equilibrium just like this vapour and the liquid they are in equilibrium not this vapour not with this liquid, although this condenses and takes place at some condenser temperature  $T_C$ . Similarly, there is  $T_1$ , at this  $T_1$  this vapour is in equilibrium with this liquid which is leaving not this vapour is in equilibrium with this liquid which is at this temperature  $T_C$ .

Similarly, for this liquid we have the specs  $L_{N P}$ ,  $Y_{N P}$  and we have  $H_{N P}$ . Now it is very important that any of the columns like this we mark and give some nomenclatures. For  $N P + 1$ ,  $N P$  last plate or we have  $Y_1$ . So, this is  $X_1$  and this will be  $L_1$  here and there will be  $H_{L_1}$ . So, at least for the top plate, for the bottom plate, for the feed  $Z$   $F$  etcetera we mark these points.

Now, the composition is given 30 percent, the first thing is we should note that it is given as weight per weight. So, we have to convert all of this quantity into moles, mole fractions that is the way we have to do it because enthalpy diagram  $H$  x  $y$  diagram are mostly given in this mole fractions. If it is given in the weight fractions then one can work on these quantities, but in this problem we are going to give  $H$  x  $y$  diagram all of this in these mole fractions. So, we have to convert all compositions for the feed or for

the top and the bottom product into mole fractions. So, this is your top product is also given as 4 percent weight by weight.

So, let us first convert Z F into mole fractions. So, we have Z F 30 over 46. This 46 is a molecular weight we have binary components here 30 by 46 over 30 by 46 plus 70 over 18. So, this is molecular weight of water if you do this we should get a quantity at 0.14. Now, for these compositions mole fractions and temperature is fixed as 40 degree centigrade, one can also obtain enthalpy of H F, we will talk about this. Similarly, let us convert this 4 percent of x w which is weight by weight into mole fractions. So, that would be 4 by 46 over 4 over 46 plus 96 over 18 to make this quantity 0.016, right. Let us say x 0 is also given as 0.74 as mole fraction, one can also of course, calculate from weight fraction to mole fraction for this the way we have done for x w and we have done for Z F.

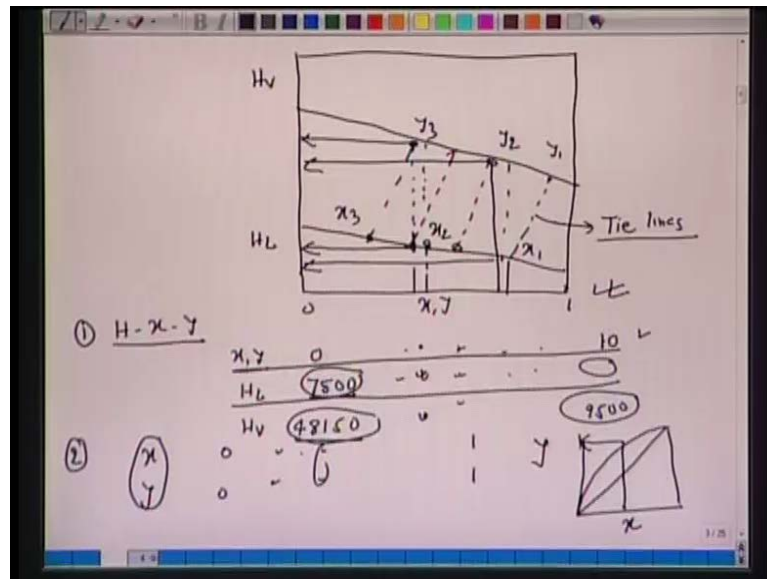
Now, we write using this nomenclature Z F, because it is very important that we understand the state of this feed here if the temperature is given T 40 degrees centigrade and the mole fraction is given here one can also calculate the enthalpy for the feed to see whether it is a cold feed or it is a composition of liquid plus vapour or it is vapour. For this problem let us say that H F is given as 4790 kilo joule per kilo mole, and it is a cold feed. So, we will see that this line is coordinate for this H F corresponding to this X F Z F which is now X F, it falls below this saturated liquid enthalpy.

So essentially, we have marked the composition of F feed marked whatever quantities are known here x w, x D here top product, notice y 1 is same as x D same as x 0. We have put some specs for the vapour which leaves the top plate, and the product which is withdrawn here the feed, the liquid which trickles from the bottom plate N P total number of plates and the vapour which leaves the boiler and at arrives at N P number of plates. Question ask in this problem is given H x y diagram and x y diagram to equilibrium specifications number 1 total number of plates or stages and without saying it is ideal stages. So, we are not talking of any Murphy efficiency etcetera. How many numbers of stages are required? The question number 2, what is the boiler load and what is this condenser load? So what is Q B here and what is Q C?

These are the two quantities we are supposed to evaluate in this example. So, what we do we have mole fraction everything in fact this feed is 5000 kg per hour and it is also important that we convert this feed to mole per hour. F is 5000 kg per hour this can be

converted into 5000 divided by the average molecular weight of this feed, this would be 227 kilo mole per hour. How do we get molecular weight F? Molecular weight of F, if you know the feed composition it is 30 percent, one can make this calculation here 30 by 48 plus 70 of 18 divide by 100 to obtain this average molecular weight as 22 kg per kilo moles. So we have converted all quantities feed all the weight fractions into mole fractions.

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Now, let us look at H x y diagram we are supposed to plot H x y diagram. This H x y diagram has to be obtained for this mixture binary component mixtures from some handout or from it has to be calculated from some co-relations. So far as very often one common way of reporting is H x y diagram is a table. We have a table, I will just note down one or two points. It is written like x y then you have a column for H L, H V. So, you will expect that x y go from 0 to quantity like 1.0, and you will have some number, so may be say 7500 just one number, 48150 may be, **may be** here we have some 9500 etcetera. That is not important, more important is we try to understand that when we report x y diagram like this, you will choose these numbers x 0 to 1, x or y and we plot H L saturated liquid enthalpy and saturated vapour enthalpy H V and HL.

Now suppose, you have chosen some point where x and y to obtain x to mark this coordinate H L. So, corresponding to this x we have some H L and some H V. Note that these two points are not in equilibrium. So, you must not understand that this is not a tie line. For every x or y whatever numbers we get plot like this, these are not the tie lines, these are not the equilibriums. Tie lines would be like this. So, for this y there will be

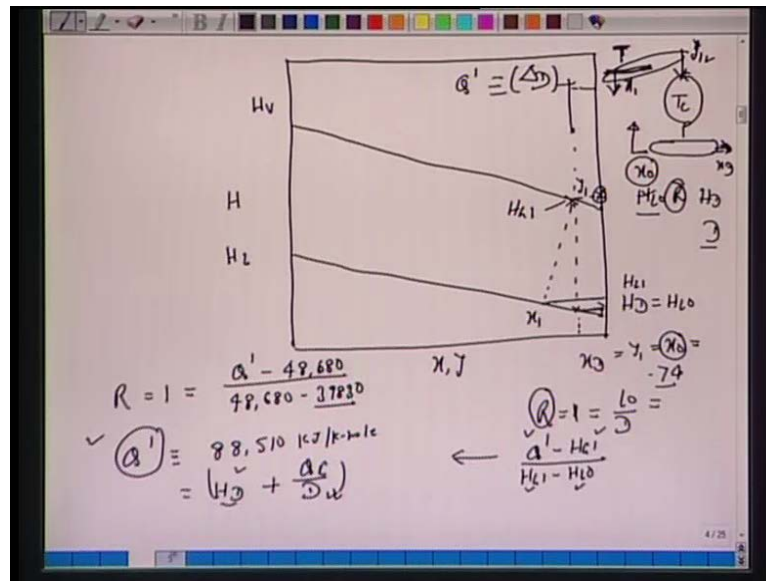
another  $x$ , for this  $y$  there will be another  $x$ , for this  $y$  there will be another  $x$  these are the tie lines that means we require one more data set for  $y$  versus  $x$  which will go from 0 to 1 and 0 to 1.

Now, if we choose  $x$  and  $y$  and mark like this, these are the tie lines. So, this is  $y_1$  or  $y_2$ , this is  $x_2$ , this is  $y_1$  and  $x_1$ . So here, for this Ponchon-Savarit method we require 2 types of equilibrium diagram or equilibrium information on the equilibrium. The one is  $H$  vs  $y$  and very often  $H$  vs  $y$  is reported like this you will have one row going from 0 to 1 another row going from  $H_L$  saturated enthalpy of a pure components to like another pure components saturated vapour enthalpy from one component to another components. You can always go through the various handbooks to obtain this  $H$  vs  $L$ .

But more important here is that for any  $x$  and  $y$  whatever numbers we choose for this these coordinates when you mark the vertically like this, they are not in the equilibrium. Equilibrium for any composition for liquid to  $y_3$ ,  $x_3$  has to be obtained from here. So, if I choose any points and we ask the question this mole for a given 2 or some mole fraction here what is the liquid, I will go to the stable may be do some interpolations to obtain this  $y$ , but the enthalpy it will be the same enthalpy as this we have to look for the enthalpy for the liquid here and the liquid vapour here to obtain in this the tie line.

So, we have equilibrium diagram like this,  $y$  versus  $x$ , so certain mole fraction of  $x$  this is equilibrium. One has to do some interpolations to plot this  $H$  vs  $y$  diagram, given the table like this; of course, if we have a plot like this we can start directly from here. Assuming that we have this  $H$  vs  $y$  diagram, we start now marking the distillation column.

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Let us plot H x y diagram again x, y and we have H here, we have plotted HV and we have plotted H L. So we start as usual say from the condenser. So, we have the condenser here total condenser and the vapour composition was y1, it gets totally condensed we have separated and we have 2 streams product. This goes as a reflux x 0 and this quantity we calculated this mole fractions, this was x D equals y 1 equals x0 equal to 0.74. This is a mole fractions the three compositions are the same because it is a total condenser.

This product we are saying that it is at bubble point, which means we mark this, this would be coordinate here on the y axis will be H D. So, this is H D and which will be same as H L 0, because part of this product is sent back as a reflux R. We are marking this coordinate here with H D and x D. Similarly, we have now this point here, so that this would be now y1. But note that this y 1 is not in equilibrium with this x 0. This vapour which arrives here, we made a statement is in equilibrium with the top plate the liquid leaving from the top plate would be x 1. So, it is in equilibrium, it is saturated with respect to this temperature plate. So, this y 1 must not be mixed, this line is not a tie line may be there is tie line which we have to read from x y diagram to obtain this x 1 on this saturated liquid, this would be x1 and the composition of x 1 will be H L 1.

We have H L 0 is enthalpy of stream which leaves here and H L 1 is the enthalpy of the saturated liquid at this temperature T. So, the T and T C are different you must understand this otherwise you make a mistake in marking the enthalpy points. This is H L 1 here and we have H L 0. Now the problem here is given that reflux ratio was given to

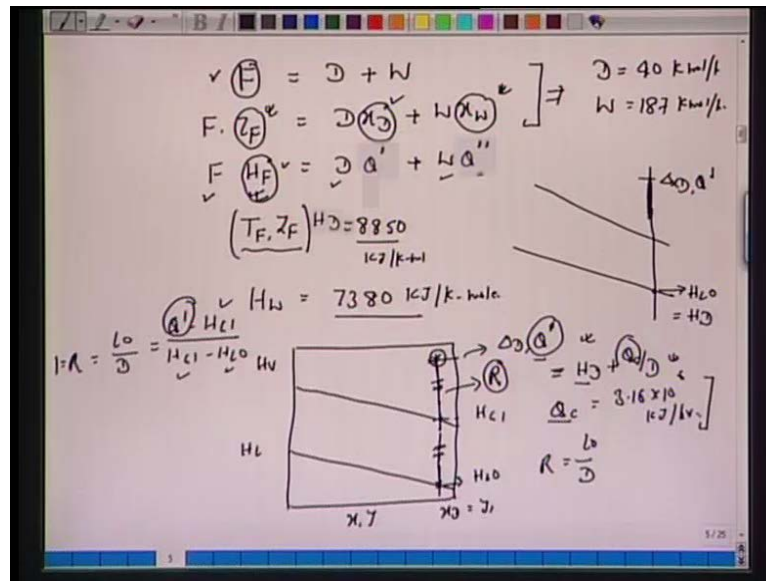


1, so we have to mark  $\Delta D$ . Notice the difference or make a note of the definition for reflux ratios is  $L_0$  over  $D$  which is nothing but  $Q'$  minus  $H_{G1}$  over  $H_{G1}$  minus  $H_{L0}$ . So, what is this point here that is  $H_{G1}$ , so this is enthalpy for  $H_{G1}$ . We know this  $y_1$ , we know this  $H_{G1}$ , we know this  $H_D$  or we know this  $H_{L0}$ , we know this coordinate. So  $Q'$ ,  $H_{G1}$ ,  $H_{G1}$  and  $H_{L0}$  they are related to reflux ratios knowing one can calculate prime.

So, we do this calculation, so that we can mark this  $\Delta D$  point,  $R$  is 1,  $Q''$  we have to calculate, minus  $H_{G1}$ . If you read from this mixture, it will turn out to be that this quantity for  $H_{G1}$  is 48680. So this is  $H_{G1}$  and we have  $H_{G1}$  minus  $H_{L0}$  - 48680 minus 39830. So, the liquid which is saturated at this condensing temperature enthalpy is  $H_{L0} - 39830$ , and this vapour which is saturated at this temperature their enthalpy is 48680.

So, from this  $R$  we can calculate  $Q'$  which we said that this  $Q'$  is enthalpy of hypothetically stream leaving this system at  $\Delta D$ , but it has energy different from  $Q_C$ . So we have this  $Q''$ , if we calculate this will turn out to be as 88510 kilo joule per kilo mole. So, we know this coordinate we can mark this  $\Delta D$  which is nothing but  $Q''$  and  $Q''$  if we recall this  $H_D$  enthalpy of this liquid saturated liquid product a saturated liquid  $H_D$  plus this is  $Q_B$  or  $Q_C$  over  $D$ . So, that is what we say this hypothetical liquid which carries an energy of  $H_D$  plus  $Q_C$  by  $D$ . So,  $Q''$  is known,  $H_D$  is known,  $D$  is known, and  $D$  we have to evaluate right now to calculate  $Q_C$ .

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Now, let us make enthalpy balance or total balance. So, we have F as D plus W, we have F Z F equals D x D plus W x W, and we have F H F equals D Q prime plus w Q double dash. So, if you see the problem statement F we calculated, F was given in kg per hour we convert into kilo moles per hour x D, we know the x D mole fractions, x W, Z F all this quantity was given to us in weight fractions and we converted into mole fractions. So, from these two we can calculate D. I leave this as an exercise, D for example, we get kilo mole per hour and we get w as 187 kilo mole per hour. So, we know from these two equations we can calculate D and w. Now, let us see F we know H F is also given to us or one can also calculate H F from this enthalpy calculation. If we know the temperature of the feed and if we know the compositions here Z F one can calculate make some balance from thermodynamic knowledge to calculate H F. Here H F we already calculated that quantity, H F is known to us H D is enthalpy of the top product. So, that is 8850.

So, if you recall your enthalpy, the previous diagram here we marked this point which was HL0 same as HD and from this we mark this point as Q dash or W, x D or this Q dash. So, 8850 kilo joule per kilo mole, reflux at the bubble point so we mark this point here. So, knowing D, W one can calculate H W. If you do this calculation it should get 7380 kilo joule per kilo mole. Now, the question comes we have enthalpy diagram let us draw it again, let us see what else we can calculate or we can evaluate from this H x y diagram. So, we have HV, HL we said we know this point which is HL0, we know this x D same as y 1, we know this H G 1. If we know this H G 1 we are looking for how do

we calculate or mark this  $\Delta W$  or  $Q_{\text{prime}}$ . So, now this  $Q_{\text{prime}}$  we said we can write as  $H_D$  plus  $Q_C$  by  $D$ . So,  $H_D$  we have calculated 8850,  $Q_C$  we do not know this condenser so, how do we mark this point. Now, you should go back and see definition for this reflux ratios  $R$  which we had calculated in our previous slides.

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We wrote  $R$  equal to 1,  $L_0$  by  $D$  all these points were known here  $Q_{\text{prime}}$   $H_{G1}$ ,  $H_{G1}$   $H_{L0}$ . So, from here one can calculate this  $Q_C$ .  $Q_C$  will turn out to be 3.16 into 10 to the power 6 kilo joule per hour. So, essentially what reflux ratio was given to us and we knew these segments. So, all we do we take the segment that is the definition for your reflux ratios  $R$  equal to  $L_0$  by  $D$ . So, if we know this  $Q$  point mark this  $Q$  point, from this  $Q$  dash we can calculate  $Q_C$  equal to this, because  $H_D$  is known and  $D$  is known to us. So, either one makes use of reflux definition for reflux ratios as  $L_0$  over  $D$  equals  $Q_{\text{dash}}$  minus  $H_{G1}$  over  $H_{G1}$  minus  $H_{L0}$ .

So, if you know the reflux ratio one these quantities are known to us we can calculate  $Q_{\text{dash}}$  which is same as from the geometry here we can calculate, we can measure this segment by a scale and we take the same scale here to obtain this  $Q_{\text{dash}}$  and from this  $Q_{\text{dash}}$  now it is equals to  $H_D$  plus  $Q_C$  by  $D$   $H_D$ . We calculated  $H_D$  is known to us here. So, we know  $H_D$  and  $H_W$  we have calculated 7380 here from this we can calculate condenser load which is the first part of this question.



segment is same as this, that is a definition for  $L_0$  by  $D$ , you can mark this point or you can write down you know the enthalpy for these two points. We can make use of this to mark this  $Q$  dash point, this  $Q$  dash point of course, we can get this condenser. Similarly, once we know this point we know this feed we can extend this line, it will be a straight line it will intersect at  $x_W$  this will give you  $Q$  dash point and from this one can also calculate  $Q$  boiler.

If you go back graphically this will turn out to be that this enthalpy here which is  $H$  or which is corresponding to this  $Q$  dash  $Q$  double dash,  $Q$  double dash or  $\Delta x_W$ . This will be minus 13068 kilo joule per kilo mole. And then if you recall the definition for this  $Q$  dash is  $H_W$  minus  $Q_B$  by  $W$ . So, here we have minus again this is plus  $Q_C$  by  $D$ . So, here we have the boiler we are giving the heat. So, we had that discussion earlier this is  $H_W$  minus  $Q_B$  by  $W$ , the enthalpy of this hypothetical stream which leaves with this  $Q$  dash. So, knowing  $H_W$  again here we have the boiler this liquid and the vapour they are in equilibrium saturated. So, knowing all these quantities  $H_B$   $W$  molar flow rates  $Q$  dash which we have calculated one can calculate boiler load as  $3.82 \times 10^6$  kilo joule per hour.

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Alternatively,

$$\frac{x_F - x_W}{x_D - x_F} = \frac{(H_F - Q^v)}{(Q^v) - (H_F)} \Rightarrow Q^v = -13,068 \text{ kJ/kmole}$$

↓  
mark pt on graph.

$$Q_B = (H_W - Q^v)W$$

$$\equiv 3.82 \times 10^6 \text{ kJ/hr.}$$

We also say that alternatively we make a note of these few points  $Q$  dash,  $Q$ ,  $F$ ,  $x_D$ ,  $x_F$  and  $x_W$ . we can apply this tie rule to write  $x_F$  minus  $x_W$  over  $x_D$  minus  $x_F$  will equal  $H_F$  minus  $Q$  dash over  $Q$  prime  $Q$  double dash minus  $H_F$ . So,  $H_F$  feed enthalpy is known this quantity is known,  $Q$  dash is known that was your top product, this is  $Q$  dash this was a top product here,  $Q$  dash is known  $x_W$ ,  $x_D$ ,  $x_F$  all quantities are known here

one can also calculate analytically  $Q$  dash minus 13068 kilo joule per kilo mole. So, it is up to you whether you calculate from here you mark the point on the graph or directly from the graph you calculate to get this  $Q$  dash, and from this  $Q$  dash. One can calculate boiler which we did earlier, get this  $H W$  minus  $Q$  double dash into  $W$ , just rearranging different ways to obtain 3.82 into 10 to power 6 kilo joule per hour. So, before we do the second part of the question, how many number of plates are there? Let us summarize what we have done.

The problem statement first you have to read the problem very correctly and you have to realize that what is the state of your condenser, in other words the reflux which goes back to the column. It is the sub cooled liquid or it is a saturated liquid here, the problem says that the vapour is a first thing is a total condenser. Entire vapour is completely condensed now when one condenses one can still cool. So, if the condenser temperature is  $T C$  the vapour can be condensed to the saturated liquid and one can further go for you know for the decrease the temperatures.

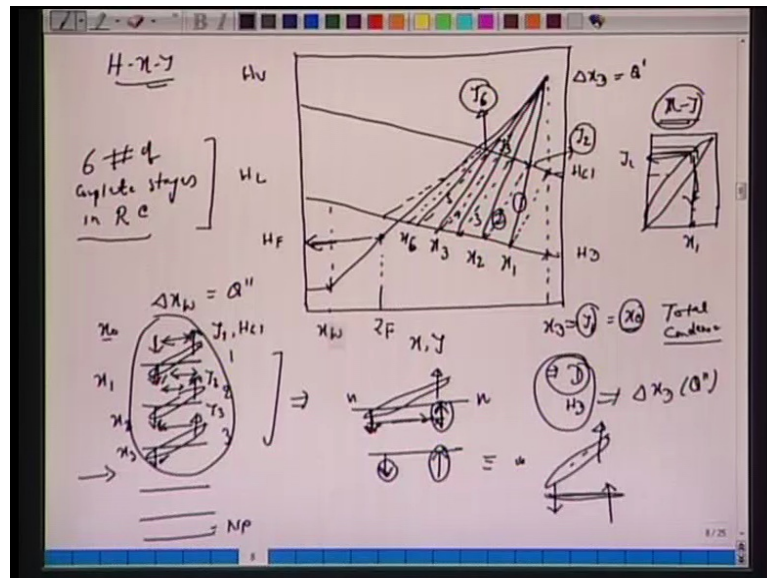
So, here the problem rate that is the saturated liquid that means reflux coordinate of reflux  $H L 0$  or corresponding to  $x L 0$  or  $x 0$  will lie at this bottom points. So, we have marked  $y 1$ , we have marked  $x 0$ . So, these two enthalpy coordinates are marked here then problem says that reflux ratio is given as 1, now when the reflux ratio is 1 reflux ratio nothing but  $L 0$  by  $D$ . So, either from the graph you can take the segment and you can mark the second points which is your  $Q$  dash points or you can make the definition for reflux ratio in terms of the enthalpy  $Q$  dash minus you know  $H F$  or  $H G 1$  and  $H D$  minus  $H G 1$  etcetera to calculate in the top points.

So, either you do graphically or you know solve it to get your  $Q$  dash point the energy or the enthalpy of the stream which leaves the top product. So, we mark this point here remember we have not a still gone into distillation column, we have not started the first one is your we are marked the points corresponding to the condenser. The top product the vapour which arrives at the condenser is in equilibrium with the liquid which trickles from the top plate. So, that is stage one that we have not got into this all we have done we have marked 1 2 3 points. Then feed composition was given of course, we converted all the composition which was given in the weight fraction into mole fractions.

So, that is the first thing we have to do, because we have to realize that all  $H x y$  diagram and  $x y$  diagram, there also given your mole fractions. So, once we have those, we mark

your  $x_F$  and  $H_F$ . So, you realize that this feed  $H_F$  is slightly cold. Now, once  $H_F$  is marked here and we have  $Q_{dash}$  marked, one can extend this line to get your  $Q_{dash}$ ,  $Q_{double}$  again from the graph we can get immediately, if you take a scale and connect these 2 points we can get  $Q_{dash}$ , once you get  $Q_{dash}$  we can do more calculations or alternatively we wrote down the expressions for  $Q_{dash}$  and from there we can calculate  $Q_B$ , and then we can mark those points there. Either way with the graphically or from this equations you know whatever expressions you have for the reflux ratios or by applying the mixing rules whatever you have for  $Q_{dash}$  or  $Q_{single}$  or  $Q_{prime}$  one can do the calculations, etcetera.

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Now, what we do is we start marking the number of the stages within the distillation column. Mark this  $H \times y$  diagram, we can start from the same graph which you had earlier. So, we have this  $x, y$ , and we have this  $H, V$ , and we have this  $H, L$ . We have already marked the condenser. So, we have this  $x, D$  same as  $y, 1$ , here we have  $H, G, 1$  and here we have  $H, D$ , this is the difference point  $\Delta x, D$ ; we have this line going through this feed. If you look at this carefully this feed composition corresponding to  $Z, F$ , and the enthalpy this feed is cold. So, this feed coordinate you will see that it will not lay on this enthalpy any way that is not important. We have we saying that  $\Delta x, D$  corresponding to this  $H, F$ , see its extent then we have intersection with  $x, W$  line, here vertical line to obtain this  $Q_{dash}$ , which is equivalent to your  $\Delta x, W$ . So, we have this  $Q_{dash}$ ,  $\Delta x, D$ .

Now, we are talking of plates here. So, we have been asked to find out how many plates are there, are required starting from 1 and we have this  $N, P$ . Now we have this vapour

leaving here which has a mole fractions  $y_1$  which we have marked here at H G 1 with enthalpy H G 1 and we have the liquid which leaves as a composition  $x_1$  mind you what  $x_D$  is same as  $x_0$  or the mole fractions of the reflux is goes into the column.

So, this is  $x_0$ ,  $y_1$  and  $x_1$  they are in equilibrium. Any time we have this vapour which leaves a plate 2 say composition  $y_2$  is in equilibrium that the liquid which leaves is stays for this 2. So, these two are in equilibrium tie lines be corresponds to this  $x_1$   $y_1$  and the operating line will corresponds to this  $x_0$  and  $y_1$  or  $x_1$  or  $y_2$  or we have here say for the third stage we have 3, we have this is  $x_3$ , we have this  $y_3$ , again these two streams will be in equilibriums and the tie line and the operating line will give you  $y_3$  and  $x_2$ .

So, with that understanding we start from here. So, this is  $y_1$ , this is your  $x_D$  corresponding to this we have  $y_1$ . Now,  $y_1$  is in equilibrium with  $x_1$ . So, we draw this tie line. Now how did we get this  $y_1$  and  $x_1$  recall that we required this T x y diagram also, we have been given 2 equilibrium data, one was on H x y and one was on this T x y on x y diagram.

From here we read  $y_1$  whatever the value of  $y_1$  is. So, this is  $y_1$  we will get  $x_1$  knowing  $y_1$  we will read from this graph as  $x_1$  we obtain this  $x_1$ . So, this will correspond to stage one, so look at this stage 1, vapour leaving is in equilibrium with this liquid. We have  $x_0$  same as this  $y_1$ , first one reflux concentration is same as the vapour which was leaving the top plate, it is a total condenser. The stages starts from here - first stage, now we know this difference point we can connect this  $x_1$  to this difference point; essentially what we do here when we connect this  $x_1$  knowing this  $x_1$  we can find  $x_2$  that is an operating line. So, this is  $x_1$ , this is  $y_1$ , we obtain this  $y_2$  or H G 2, this is what the way we are moving  $y_1$ ,  $y_2$ , we have  $x_0$ ,  $x_1$ . Now this  $y_2$ , stage 2 it is in equilibrium with the liquid which leaves this stage 2.

So, again we have to come this x y diagram obtain this  $y_2$ , wherever it is get another  $x_2$  here and we mark this point. So, we have to make use of both H x y diagram as well as this x y diagram both are a this is mole fractions this also is the mole fractions. So, knowing this now we have  $y_2$ , now we obtain this point which is  $x_2$ . So we are here again  $x_2$  and  $x_D$  we connect to obtain this  $y_3$ , again try to understand that from previous discussions but any tray which we take say in the rectifying sections liquid leaving and the vapour leaving they are in equilibrium but the molar flow rate of liquid



and the molar flow rate of the vapour which arrives. The two difference is always a constant here given as top product which we have D.

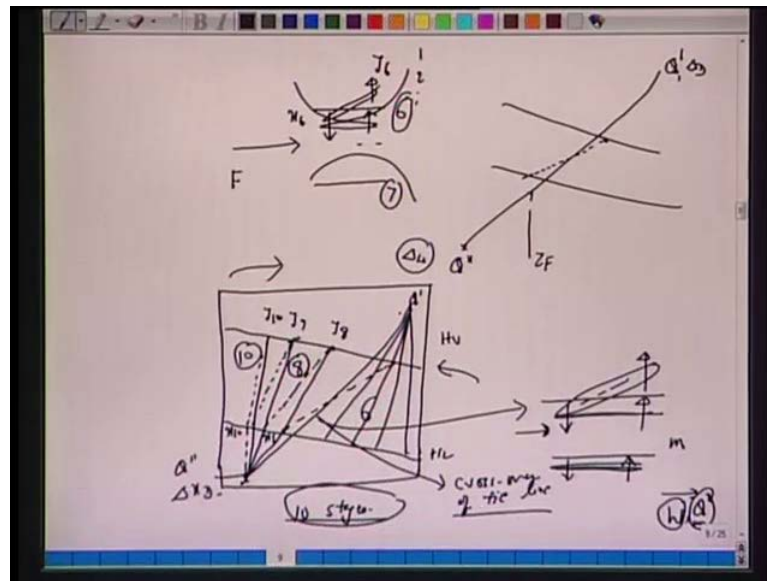
Similarly, the enthalpy difference between this vapour which arrives at any plate N and the liquid which leaves that plate N have the same difference given as H D. So, that is what it correspondent to this difference point  $\Delta x D$  or Q dash. So, we mark that point and whatever we connect the solid lines these are now operating lines and the dotted line these are now stages. So, number of stages 2 it marks here y 3 then we have to come back to this see where it is y 3 corresponding to this we get x 3 we connect with this we get the second next operating line.

Whatever is happening physically on this stages must also happen on this graph, here dotted line connects the 2 leaving streams and the operating lines solid line which passes through this common point x D. Why it is common? Because the difference between the molar flow rate of the vapour arriving that plate and the liquid leaving that plate is a constant. Enthalpy of this vapour which reaches this plate and the enthalpy of the liquid which leaves that plate is also a constant. By applying this mixing rule we have obtain these common points. So, whatever we do the calculations here we also getting physically on this stages, we are going from column we are going from liquid if we start from the liquid we will go to the vapour to the liquid by operating then from the liquid to the vapour by tie line then from the vapour to the liquid by this operating line, all right.

So, our movement on the stage wise is like this, let us do it again vapour and the liquid like this. So, these are the operating lines and the vapour which leaves and the liquid which leaves that is an equilibrium line that is a tie line and this is a solid line. So, one time tie line, one time solid line we connect all these points and it turns out to be that here if we keep on connecting then we have one more. So, we have 1, 2, 3, 4, 5, etcetera connect with this we will get a total of 6 number of plates.

So, x 1, x 2, x 3 finally we have x 6 and here we have this y 6. So, at last all it means there are 6 numbers of complete stages in rectifying column or rectifying sections. You should be able to convince yourself, you have done graphically that there will be 5 tie lines, the seventh line which you connect with the solid line what will happen if we take a tie line this will in cross this the line which goes through the feed line all it means now we have arrived.

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Let us look at another schematics here, we have feed and rectifying sections and stripping sections. So, this is a last plate which we are saying that this is your 6 stage starting from here 1, 2, dot dot dot, we have the 6 stage vapour arrives, the 6 stages and the liquid leaves the 6 stage. At last stage you will get here and the vapour which leaves here will be in equilibrium with this, this is  $y_6$  and  $x_6$  on this graph with the previous graph say this was your line which went across which was meeting  $Q$  dash and  $Q$  double dash with  $F$  here  $Z F$  or  $x F$ , the feed points you should be able to obtain 6 complete stages, seventh stages you will see that the tie line it crosses the big line. Now we are here, that means now we have completed your rectifying sections and we have to work on this  $W$  instead of  $\Delta W$ . 50.09

If you continue with the same  $H \times y$  diagram, now we have to switch we have to step down to this stripping sections. So, qualitatively if we draw again  $H V$  and we have  $H L$  mark this point we have this  $Q$  dash and  $Q$  double dash. We completed 6 stages here, the last one we are drawing tie line, now it has intersected. So, that is the feed locations, feed is in between 6 stage here and the next stage we have to continue from here then this would be your eighth seventh if you leave for this feed entry or may be if you call this as a seventh stage. So, the feed enters between sixth and seventh.

So, once we reach this now instead of connecting to this  $Q$  dash now we are in this **(C)** now we have to connect to this. Of course, this line can be solid line can be extended to obtain second stage, now we are in this stages in this stripping sections and here we have to do the same thing now we have this liquid this tie line which connects here take this

liquid tie line. So, that would be the stage number 8 connect with this to obtain here now another mole fractions we take a tie line stage 9 and we connect here to obtain this will connect finally to our top bottom product this number stage number 10.

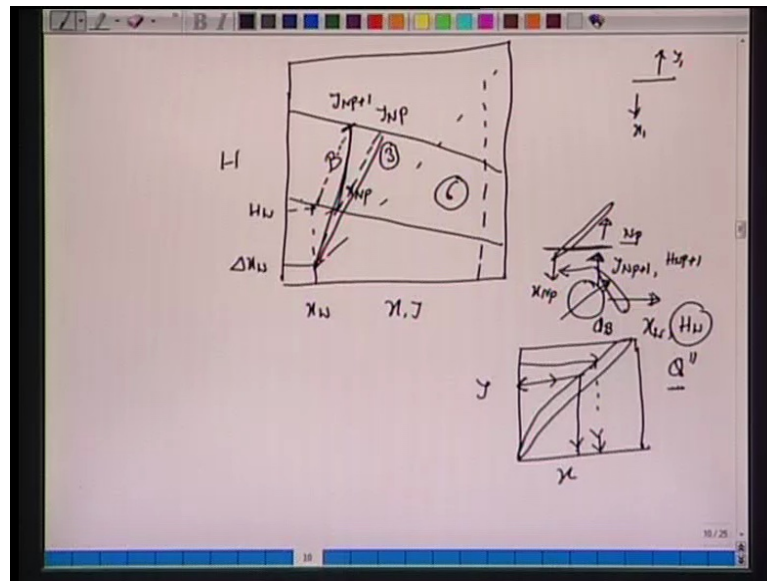
So, whatever operations we have done for this rectifying sections, we are doing for this stripping sections and here we have the same mechanism same scenarios the liquid which leaves the plate is in equilibrium with the vapour. So, this would be in the tie line and the liquid and the vapour which arrives with this liquid here this would be the solid line.

So, now the difference point is even with this  $Q_B$  with respect to the bottom product which is your  $W$  and the there is enthalpy of this  $Q_{dash}$ . So, whatever we choose any  $m$ th plate liquid vapour arriving here and the liquid leaving here the difference between the two enthalpy as a molar flow rate is conserved with the  $W$  and the  $Q_{dash}$  which we have marked this as a  $\Delta x D$  points.

How many plates are required? If we do it carefully we require 10 numbers of stages. There is a crossover at this point there is a crossover of tie line. That is a very important that we mark this point that is a location of the feed enters just after the 6 stages which we are completed, all right. That is an entry of the feed and once we cross this feed we are now in this rectifying sections, stripping sections then we are going to connect with this and we continue marking our data points like  $y_1, y_2$ , we have this  $y_8$  this corresponds to  $x_8, y_9, y_{10}, x_{10}, x_9$ , etcetera.

Now there is one more thing here, one can start from this point also instead of going starting from the top product we can also start from this bottom. Once again when we cross this line here this feed line one has to do the calculations connecting with this top products, all right. So, on this example what we have done today we have addressed complete distillation column including the condenser and the boiler. In the condenser it was a total condenser. So, we did not have any theoretical stages for the top for the bottom is always a boiler is always a theoretical stage. So, here also the last tie line which will cross this  $x_W$  will also represent theoretically stage for the reboiler.

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Let us complete our discussion with the last stage here. So, we redraw this  $H \times y$  diagram, now we focus on this stripping sections, this is  $x_W$ , let us say this is your  $\Delta x_W$   $W$  which you have obtained by connecting feed etcetera.

Now the bottom product when we withdraw this  $D$  the liquid which goes out from this is in equilibrium with the vapour reflux is goes to that bottom column, bottom plate of this column. And here we said that this is  $y_{NP+1}$ ,  $H_{NP+1}$ , so this plate is  $NP$ , because this boiler acts as a theoretical plate. So, if we start from here we must note that this  $x_D$ , let us correct this to  $x_B$  bottom product or  $x_W$ , and we had this  $H_W$ . So, these two streams are in equilibrium.

So, we start from here, this is we can also start from here should be now  $H_W$ , and now this liquid is in equilibrium with this vapour. So, if we start from this side we have the first tie line, this tie line will corresponds to boiler, and here we have this  $y_{NP+1}$ . So, this boiler is equivalent to partial condenser which we had discussed a couple of lectures. So, the first stage we have marked is as a boiler, now we can connect this  $y_{NP+1}$  plus 1 to this. So, when we are seeing that we are connecting this  $y_{NP+1}$  essentially we are connecting with this  $x_{NP}$ .

So, this is the liquid composition which comes from  $x$  from the bottom plate  $NP$ . So, solid as usual the definition for this operating line is that now we are connecting  $y_{NP+1}$  plus 1 with  $x_{NP}$ , now this  $x_{NP}$  is in equilibrium with  $y_{NP}$ . So, again we draw this tie line to this  $y_{NP}$ , and how do we get this 2 mole fractions again one has to rely on this  $y$

x. We have to make use of both equilibrium plot  $H \times y$  as well as  $y$  versus  $x$  diagram. So, every time we have to read  $H \times y$  we have to come back take this  $x$  find  $y$  or take this  $y$  and find  $x$ .

So, if you go from this side, for every liquid  $x$   $N P$  mole fractions we have to come back here take the mole fraction of heat go like this unlike in the previous case where we are starting from the top we started from the vapour knowing the vapour compositions etcetera, we got into this. Because in the top plate vapour leaving was in equilibrium with this  $x_1$ , so we have  $y_1$  and  $x_1$ , there we started from  $y_1$  and we got  $x_1$  in this case we have to start very often in the stripping sections from  $x_1$  and get  $y_1$ .

So if you do this we can connect with this again this is solid light idea is that molar difference between the two flow rates is same enthalpy difference between the two plates is same as your  $Q$  double dash. So, if you do this we will have 6 plates here, and we will have 3 plates. So, either way one can start from here one can start from here depending upon the type of the problems.

So, this will be the end of this example here where more or less we have been able to address entire top column s and also rectifying section, stripping sections. How to calculate the  $Q_B$ ,  $Q_C$  condenser load? How to calculate this boiler load? How many plates are required? We can do the graphically, we have to be careful wherever we intersect this feed line you know the connecting between  $Q$  dash and  $Q$  double dash, one has to switch from  $x_D$  to  $x_W$ . Similarly, if we start from here then as soon as you cross the tie line cross to this feed line we have to start connecting with this  $x_D$ . So, this is one example, in the next class again we will take another example where we will address certain quantities like minimum number of flux, minimum number of plates required or total reflux minimum, minimum reflux ratio etcetera. What are the corresponding  $Q_B$  and  $Q_C$  for those cases? Thank you.